EFFECTS OF STIMULUS FREQUENCY AND REINFORCEMENT VARIABLES ON REACTION TIME

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Pigeons pecked at one of two black forms, "+" or "o," either of which could appear alone on a white computer monitor screen. In baseline series of sessions, each form appeared equally often, and two pecks at it produced food reinforcement on 10% of trials. Test series varied the relative probability or duration of reinforcement or frequency of appearance of the targets. Peck reaction times, measured from target onset to the first peck, were found to vary as a function of reinforcement probability but not as a function of relative target frequency or of reinforcement duration. Reaction times to the two targets remained approximately equal as long as the probability of reinforcement, per trial, was equal for the targets, even if the relative frequency of the targets differed by as much as 19 to 1. The results address issues raised in visual search experiments and indicate that attentional priming is unimportant when targets are easy to detect. The results also suggest that equalizing reinforcement probability per trial for all targets removes differential reinforcement as an important variable. That reaction time was sensitive to the probability but not the duration of reinforcement raises interesting questions about the processes reflected in reaction time compared with rate as a response measure.

Key words: visual search, attention, priming, contrast, reaction time, reinforcement probability, reinforcement duration, peck, pigeon

In visual search, repeated exposure to one target can cause a subject to find that target efficiently, relative to other targets not seen as often (P. Blough, 1989, 1991; Bond, 1983; Pietrewicz & Kamil, 1979; Tinbergen, 1960). For example, if on repeated trials a pigeon searches for and finds a particular item, such as a grain of corn or an "A" displayed on a computer monitor, its search reaction time to that item is reduced on subsequent trials, relative to reaction times for alternative targets (P. Blough, 1991; Bond, 1983).

In seeking an explanation for this repeated-exposure effect, one might look first for differential reinforcement. Perhaps the target is responded to more rapidly because that response has frequently been reinforced; not surprisingly, search reaction time is indeed sensitive to reinforcement probability (D. Blough, 1989). However, recent studies have found the repeated-exposure effect despite measures to equate reinforcement for alternative targets (e.g., P. Blough, 1989, 1991; Pietrewicz & Kamil, 1979). Thus, the most commonly accepted explanation of the repeated-exposure effect is perceptual. Ac-

cording to this view, repeated exposures induce a temporary perceptual readiness or attentional state, which enables the searcher to see the target more rapidly. In support of the attentional interpretation, the effect has been found to be sensitive to variables related to detectability, such as the number of alternative targets and the number of items in a search display. Experiments with humans provide additional evidence; for example, Davis, Kramer, and Graham (1983) found that repeated presentations of one target enhance the detectability of that target over alternatives.

Most laboratory investigations of the repeated-exposure effect have emphasized attention, and perhaps in consequence boundary conditions for the phenomenon have not been fully tested. Does repeated exposure still influence search reaction time when attentional influences are minimized? If so, the attentional account is weakened. What is the appropriate way to equate targets for reinforcement under conditions of repeated exposure, equal *probability* across targets or equal *frequency* across targets? The present study approached these questions as follows: Target detection was made extremely easy, so that variation in perceptual efficiency (attention) should have little effect. Reinforcement probability and duration were varied; equal probability and equal frequency conditions were compared.

Table 1

Experimental conditions.

Series	Session	Frequency o	Frequency +	Reinforce-ment o	Reinforce-ment +	F^a	p
1	5	.5	.5	.1	.1		
2	7	.5	.5	.3	.1	345	.003
3	5	.5	.5	.1	.1		
4	7	.5	.5	.1[b]	.1	0.81	.46 (ns)
5	4	.5	.5	.1	.1		
6	7	.1	.9	.5[c]	.056	242	.004
7	5	.5	.5	.1	.1		
8	7	.1	.9	.1	.1	7.8	.11 (ns)
9	5	.5	.5	.1	.1		
10	7	.95	.05	.1	.1	0.78	.47 (ns)
11	7	.5	.5	.1	.3	18.4	.05
12	5	.5	.5	.1	.1		

Note. Underlining indicates key changes in independent variables.

[a] ANOVAs compared experimental series with the preceding and following baseline series taken together, except that Series 9 and 10 were compared and 11 and 12 were compared.

[b] Reinforcement duration varied (see text).

[c] These proportions yield equal absolute numbers of reinforcements for the two targets (see text).

METHOD

Subjects

Three male White Carneau pigeons served. They all had served in several search tasks, in which they had discriminated among a variety of forms. The birds were maintained at approximately 80% of their free-feeding weights, and they normally received their entire food ration of mixed grain during experimental sessions.

Apparatus and Stimuli

Birds were trained and tested in operant conditioning chambers, two with interior dimensions of 31 cm by 35 cm by 35 cm and one with dimensions of 35 cm by 35 cm by 40 cm. Directly above a centrally located feeder was a black-and-white video monitor that measured 13 cm diagonally. The screen was overlaid by a frame that left a window (10.5 cm by 6 cm) exposed. Recessed in the top and bottom of this frame were rows of infrared detectors and emitters that permitted the localization of pecks to the screen within six contiguous vertically oriented strips or response segments. ATARI 800® personal computers provided control and data recording. Additional details of the display and response sensing systems are provided in D. Blough (1986).

Stimuli were two black forms presented on an otherwise white background on the computer monitor screen: a "o" and a "+," each 3 mm in height and width. One of these targets appeared alone on each experimental trial. The forms were highly discriminable from each other to the human eye.

Procedure

Experimental sessions consisted of many brief trials separated by 2-s intertrial intervals. A trial began when a target appeared on the screen. When two successive pecks were made to the same response segment (defined above), the screen became blank white and remained white until the start of the next trial 2 s later. If the two pecks were made to the target form (as was almost always the case), a correct response was recorded, and food was presented after the second peck on some fraction of trials (as described below). When food was given, the feeder was activated for approximately 2 s, with the feeder time adjusted to hold each bird's weight approximately constant across days. The time from stimulus onset until the first peck was recorded as a reaction time to the nearest 60th second. If the pecks were made to a nontarget region, food was not given and the data were discarded.

Experimental sessions were conducted at approximately the same time daily, and each lasted from 1 to 2 hr. A session consisted of 90 blocks of 20 trials each, with an exception noted below. Each target appeared either equally often (10 times) in a block, or in

the proportion specified in the conditions outlined below. Because the birds were highly practiced at pecking at visual targets in this apparatus, no pretraining was necessary.

Table 1 shows the experimental conditions across the 72 sessions of the experiment. On each trial, one of the two targets appeared alone on the screen, in either of two locations to the left and right of the center of the screen. For example, in Series 1 (top line, Table 1), the birds worked for five sessions on a procedure in which each block of 20 trials included 10 trials with each target (relative frequency .5 for each target), and for each target one of these 10 trials yielded food reinforcement (probability of reinforcement .1 for each target). Variations of frequency and reinforcement in all the series followed the 20-trial-block scheme; for example, when one target appeared with a relative frequency of .95 (Series 10, Table 1), it appeared on 19 trials in each 20-trial block. In Series 4, the duration of food presentation was doubled to approximately 4 s, the exact duration depending on the bird's baseline duration. This duration change more than doubled food intake per reinforcement; a reduction in the number of blocks of trials per session from 90 to 60 partially compensated for this increase.

RESULTS

The primary data were mean reaction times for each session, target, and bird. For the last three sessions in each of the 12 series (Table 1), the difference in log mean reaction times for the two targets was tested statistically. Separate mixed model ANOVAs tested for differences between results from experimental series (differential presentation frequency and/or reinforcement frequency) and the baseline series (equal frequency of presentation and of reinforcement) that preceded and followed. For all ANOVAs, $df = 1, 2$ (targets, targets × birds); F ratios and probabilities appear in Table 1.

The session-by-session results are summarized in Figure 1. Mean reaction time across sessions is shown for each bird in the top three panels; the geometric means of these data across birds are shown in the bottom panel. Several aspects of the data are notable. First, a three-fold increase in the frequency of reinforcement associated with one target
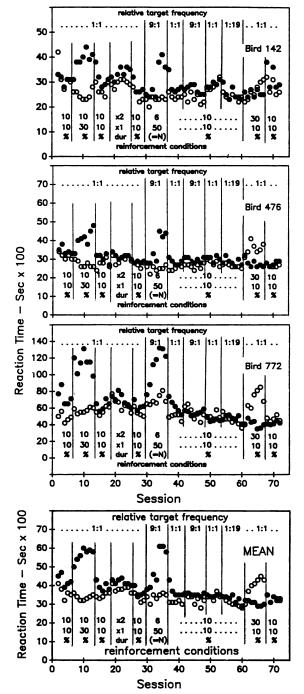
Fig. 1. Mean reaction times for the two targets across sessions. Open circles, target O; filled circles, target +. Data for individual birds appear in the top three panels; the geometric mean of the 3 birds appears in the bottom panel. The relative frequency conditions and reinforcement conditions for each series of sessions are indicated; for details, see text and Table 1.

(from 10% to 30%; Series 2 and 11) generated no consistent change in reaction times to that target, but lengthened reaction times to the other target substantially (second panel from left and second panel from right). The difference in reaction time was clear in all 3 birds and was statistically significant whichever target was more frequently reinforced (Table 1, Series 2 and 11). Second, doubling the duration of food presentation for pecks to one target (Series 4) had no significant or suggestive effect on reaction time to either target. In addition, presentation of one target either 9 times (Series 8) or 19 times (Series 10) as often as the other yielded no significant effect on RT to either target. Finally, changing both presentation frequency and reinforcement frequency in such a way as to keep equal the absolute number of food presentations associated with each target (Series 6) yielded the same substantial effect as the simple change in the probability of reinforcement. This effect was clear in all birds and was statistically significant (Table 1).

DISCUSSION

The data provide partial answers to several questions raised above. First, reaction time was insensitive to relative target frequency under conditions that minimized the possibility of an attentional influence on search speed. On its own, this lack of effect might mean little, but in conjunction with experiments run under similar conditions (except that targets were hard to find and attention could play an important role; e.g., P. Blough, 1989, 1991), the result strengthens the attentional interpretation of the repeated-exposure effect. Second, search speed was strongly linked to reinforcement probability (i.e., reinforcers per trial or per unit time) associated with a stimulus, rather than to the total number of reinforcers associated with the stimulus or the frequency of appearance of the stimulus. This sensitivity to reinforcer probability is surely one of the most important and general findings in conditioning (e.g., Gibbon, 1981; Herrnstein, 1970; Jenkins, Barnes, & Barrera, 1981). The present results therefore strongly suggest that reinforcement-generated bias in search and similar situations will be minimal where equal reinforcement probability across conditions is assured. Third, the sensitivity of reaction time to reinforcement probability contrasted with its insensitivity to reinforce-

ment duration. Relative response rate to stimulus components in multiple schedules appears to be sensitive to both variables (e.g., Ettinger, McSweeney, & Norman, 1981). Because one might otherwise expect that some common process underlies the influence of reinforcement on both reaction time and rate, it would be worth studying the effect on reaction time of a wider range of durations and possibly qualitative reinforcement variables as well. Differences in reinforcement effects on reaction time and response rate suggest that these measures reflect different, though probably overlapping, mechanisms.

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